

A DEVICE FOR CONTROLLING THE STATE OF CHARGE AT CONSTANT  
VOLTAGE OF A BATTERY OF SECONDARY ELECTROCHEMICAL CELLS

The invention relates to the field of electric  
cells, and more particularly to the field of secondary  
5 electrochemical cells, more commonly known as  
rechargeable batteries (or battery units).

Rechargeable batteries are generally constituted by  
a plurality of secondary electrochemical cells (also  
known as storage cells, rechargeable cells, or indeed  
10 accumulators), connected in series and/or in parallel.  
Such batteries are commonly intended for powering  
electrical equipment, also referred to as "applications".

Amongst such batteries, some are known as being  
"maintenance-free" and are required to present very long  
15 lifetime, typically a few years to a few tens of years.  
This applies in particular to alkaline batteries of the  
nickel/metal-hydride (Ni/MH) type and of the  
nickel/cadmium (Ni/Cd) type, or to batteries of the  
lithium/ion (Li/Ion) type, or of the lead-acid (Pb/PbO<sub>2</sub>)  
20 type.

In order to achieve such performance, those  
batteries are generally coupled to a battery charger  
suitable for feeding them with electricity when their  
state of charge so requires. However, the active  
25 materials of which such batteries are made tend to  
deteriorate more quickly when their mean temperature is  
high and when they are subjected to too many poor  
detections of end-of-charging (or abusive overcharges).  
As a result, after a length of time that varies as a  
30 function of conditions of use, the charger can no longer  
suffice to maintain batteries at a level of performance  
that is sufficient for the applications with which they  
are coupled. Furthermore, constant-voltage charging of  
couples such as Ni-Cd or Ni-MH can lead to thermal  
35 runaway.

In an attempt to remedy those drawbacks, proposals  
have been made to place a control device at the interface

between the charger, the application, and the battery, the control device serving to monitor the state of charge of the battery, and in particular to attempt to prevent the state of charge firstly from exceeding an over-charge threshold, and secondly from dropping below a discharge threshold, and to do so without measuring current (since that is expensive and complex to achieve, given that it would require both small currents and very strong currents to be measured accurately).

Among the numerous control devices already proposed, two are more particularly of interest. They are described in French patent document FR 2 817 403 and Japanese patent document JP-11 225 445. They enable the battery to be subjected to intermittent charging by chopping using an electronic switch in the event of end-of-charging being detected. Although that solution is indeed of interest, it requires the current flowing through the battery to be measured continuously, and that tends to reduce its reliability and to significantly increase its cost. In addition, that solution is suitable only for so-called "constant current" chargers and not for so-called "constant voltage" chargers.

An object of the invention is thus to remedy the above-mentioned drawbacks in full or in part.

To this end, the invention provides a device for controlling the charging of a battery of secondary electrochemical cells (e.g. nickel/metal-hydride (Ni/MH), nickel/cadmium (Ni/Cd), or lithium/ion (Li/Ion), or lead-acid (Pb/PbO<sub>2</sub>) storage cells), the device being interfaced between a battery charger, the battery, and electrical equipment, and comprising: firstly measurement means for delivering measurements of a first physical magnitude representative of the voltage across the terminals of at least a portion of the battery, and of a second physical magnitude representative of the temperature of at least a portion of the battery; and secondly control means capable, as a function of the measurements of the first

and second magnitudes, of determining an electrical reference value (a current value or a voltage value depending on the type of charger) enabling the battery to be maintained in a selected state of charge and at a mean  
5 temperature that is substantially lower than a selected threshold by providing it with a continuous low current at constant voltage and without measuring said current.

In other words, the invention guarantees a maximum state of charge in a minimum length of time and this  
10 state of charge is maintained by means of a determined continuous low current in such a manner that the temperature of the secondary electrochemical cells is as low as possible in order to degrade the "instantaneous" performance of the battery as little as possible and, in  
15 some cases, in order to avoid any thermal runaway.

It is thus possible to manage the various stages of use of the battery coupled to a constant voltage charger without measuring current and while also avoiding thermal runaway.

20 The continuous low current preferably lies in the range about  $I_c/100$  to  $I_c/5000$ , and more generally lies in the range  $I_c/500$  to  $I_c/2000$ . In this case, the magnitude " $I_c$ " designates the current  $I_c$  theoretically required for discharging the battery in one hour. For example, if  $I_c$   
25 = 40 amps (A), then it represents the current equivalent of a capacity C of 40 ampere hours (Ah).

In a first embodiment, the control means may be arranged in such a manner as to send the charging reference value to the charger when the charger is fitted  
30 with an input for this purpose. Under such circumstances, it is advantageous for the control means to be arranged in such a manner as to deliver the electrical reference values to the charger using any conceivable type of protocol, for example a protocol of  
35 the pulse-width modulation (PWM) type, or a "0-10 volt (V) reference signal" protocol, or a "4 milliamps (mA)-

20 mA reference signal" protocol, or indeed by using a control area network (CAN) type bus.

In a second embodiment known as a "smart" battery, means are also provided to limit the current fed by the charger, which means are arranged to feed the battery as a function of the electrical reference value delivered by the control means.

In order to achieve standardization, it is possible for both embodiments to coexist on a single electronic card.

The measurement means preferably serve to deliver to the control means measurements of the local voltage at the terminals of at least one of the secondary electrochemical cells (and possibly all of them). It is also preferable for the measurement means to deliver to the control means measurements of local temperature in at least one of the secondary electrochemical cells of the battery.

In addition, the device may also include a communications interface coupled to the control means so as to exchange data with external computer equipment serving, for example, to modify the operation of the control means or to store operating data in order to retrace at least a fraction of events that have occurred in the battery.

The invention also provides a battery including a control device of the type described above.

Particularly advantageous applications of the invention lie in fields such as those of electrically-powered vehicles, aviation, rail transport, ground stations, handheld power tools, or telephony, in particular mobile telephony.

Other characteristics and advantages of the invention appear on examining the following detailed description and the accompanying drawings, in which:

· Figure 1 is a block diagram showing coupling between a first embodiment of a control device of the

invention, a battery, a charger, and electrical equipment;

· Figures 2A and 2B are block diagrams showing coupling between a second embodiment of a control device of the invention, a second battery, a charger, and electrical equipment, respectively during the stage of charging the battery and powering the electrical equipment, and during the stage of discharging the battery via the electrical equipment;

· Figure 3 is a block diagram of an embodiment of a control device of the invention corresponding to the block diagrams of Figures 2A and 2B; and

· Figure 4 is a flow chart for an algorithm showing one way in which the device of the invention can be operated.

The accompanying drawings may serve not only to complement to the description of the invention, but they may also contribute to defining it, where appropriate.

The invention is intended to monitor the state of charge of a battery constituted by one or more secondary (i.e. rechargeable) electrochemical cells. As an illustrative example, in the description below, it is assumed that the battery comprises  $n=3$  secondary electrochemical cells connected in series, and constituted for example by nickel/metal-hydride (Ni/MH) or by nickel/cadmium (Ni/Cd) storage cells. It is also assumed that the battery is, by way of example, for installing in an uninterruptable power supply unit of a computer center for powering its main electrical equipment in the event of a failure in the mains electricity supply. Naturally, the invention is not limited to that application, and it may be used in other fields such as aviation, rail transport, ground stations, handheld power tools, and telephony.

In order to control state of charge, the invention proposes a device 1 for placing, as shown in Figures 1 and 2, in the interface between a battery 2, a constant

voltage charger 3, and electrical equipment 4, also referred to as an application.

More precisely, in the embodiment shown in Figure 1, the device 1 controls the state of charge in the battery 2 by giving the charger 3 a voltage value (U) that is appropriate for the battery at each instant. The way this action is implemented is described in greater detail below with reference to Figures 3 and 4.

When the battery 2 needs recharging, the device 1 determines the electrical reference value that will enable the charger 3 to feed the battery 2 with an appropriate constant voltage. When the battery 2 is charged and the application 4 itself needs powering (e.g. because of a failure in the power supply to the charger), said battery 2 powers said application 4. Finally, when the charger 3 comes back into operation, with the battery 2 then being insufficiently charged, the device 1 determines the electrical reference value for enabling the charger 3 to feed the battery 2 at an appropriate constant voltage while the charger 3 simultaneously powers the application with the electricity it needs. The appropriate voltage depends on the electrochemical couple involved.

In the embodiment shown in Figures 2A and 2B, the charger delivers a given direct current (DC) to the battery 2 at constant voltage, and the device 1 controls the state of charge of the battery 2 by acting on the mean value of the current fed to the battery 2 by chopping the current in a current-limiter module 5. This chopping may be implemented, for example, by an electronic component of the field-effect transistor (FET) type. This embodiment is known as a "smart" battery.

As shown in Figure 2A, when the battery 2 needs to be recharged, the device 1 determines the electrical reference value that will enable the current limiter module 5 to feed the battery 2 at constant voltage with at least a fraction of the electricity delivered by the

charger 3. As shown in Figure 2B, when the battery 2 is charged and the application 4 needs to be powered (because the charger 3 has failed), said battery 2 feeds said application 4 via a power diode (for a very short length of time), and then via a switch connected in parallel and closed for this purpose. Finally, when the charger 3 becomes "present" again, but with the battery 2 then being insufficiently charged, said charger 3 powers the application 4 directly with the electricity it has available while, in parallel, also charging the standby battery. This state of affairs also corresponds to Figure 2A.

Reference is now made to Figure 3 to describe in detail an embodiment of the device 1 of the invention corresponding to the situation shown in Figures 2A and 2B ("smart" battery).

In this embodiment, the device 1 comprises firstly a measurement module 6 coupled to the battery 2 so as to measure, e.g. periodically, at least two physical magnitudes which characterize the battery, and in particular the voltage across the terminals of at least a portion of the battery and the temperature of at least a portion thereof. The measurement module 6 preferably delivers the local voltage across the terminals of at least one of the secondary electrochemical cells 7, and the local temperature of at least one of said secondary electrochemical cells 7.

In a less-sophisticated embodiment, the measurement module 6 might deliver only the total voltage across the terminals of the battery and the mean temperature of the entire battery 2.

The device 1 also comprises a control module 8 coupled to the measurement module 6 in such a manner as to control the state of charge of the battery 2 as a function of its own intrinsic characteristics and as a function of the measured voltage  $U$  and temperature  $T$ . It is this module which calculates the electrical reference

values that enable the current fed to the battery 2 at each instant to be governed. The electrical reference values (current or voltage) are calculated as described below as a function of the voltage and temperature

5 measurements as delivered by the measurement module 6. These reference values are proportional to the current (or voltage) needed for proper operation of the battery 2. Typically they lie in the range 0 to 1.5 volts (V) per cell (for a battery of alkaline cells).

10 The control module 8 is preferably implemented in the form of an application-specific integrated circuit (ASIC) or in the form of a programmed microcontroller (e.g. using the C language), depending on the type of battery 2 and possibly also the type of application 4  
15 with which it is coupled. In this case it is coupled to a current limiter module 5 constituted by three portions in this example. A first portion 5a is coupled firstly to one of the outputs of the charger 3 (and one of the inputs of the application 4) physically embodied by the  
20 "+" terminal, and secondly to one of the terminals of the battery 2 (whose other terminal is physically embodied by the "-" terminal and is connected to the application 4). This is a module that is capable of being instructed to reduce the magnitude of the current delivered by the  
25 charger 3. A second portion 5b converts the electrical reference value instructions delivered by the control module 8 into instructions that enable the module 5a to determine the extent to which the current delivered by the charger 3 is to be reduced. An optional third  
30 portion 5c is interposed between the output of the module 5a and the input of the battery 2 in order to protect said battery 2.

Furthermore, in order to enable the control module 8 to be reprogrammed and/or to collect operating data, for  
35 optional storage in a memory (not shown) for the purpose of recapitulating at least a portion of the events to which the battery 2 has been subjected, the device 1 may



include a communications interface 9, e.g. of the RS232 type, coupled to the control module 8 and suitable for being connected to computer equipment 10, for example a portable computer.

5        When the device 1 does not include a current limiter module 5 (or 5a-5c), and consequently corresponds to the embodiment shown in Figure 1, the control module 8 has an output (represented by the dashed line arrow in Figure 3) connected to the charger 2 so as to be able to supply it  
10        with data representative of the electrical reference values (when the charger is capable of interpreting such values). Under such circumstances, data exchange may be performed, for example, by using a pulse width modulation (PWM) type protocol, or by delivering an analog reference  
15        value of the 0-10 V type or of the 4 mA-20 mA type, or else by using CAN type bus. In such an embodiment, it is recalled that the charger 3 delivers at its output current that is variable as a function of the electrical reference values received from the control module 8, and  
20        that it does so under constant voltage, whereas in the embodiment that includes its own current limiter module 5, it is that module which acts (by chopping its own output current) to determine a current that varies as a function of the electrical reference values received from  
25        the control module 8 and as a function of the variable current (in the range 0 to I max) delivered by the charger 3 at constant voltage.

      In addition, the control module 8 may be programmed in such a manner as to manage the state of health of the  
30        battery 2. In particular, it can detect failures, and possibly even predict failures, and it can also indicate its state of charge. This information can be stored for subsequent processing by an operator, after being  
      extracted via the communications interface (e.g. of the  
35        RS232 type).

Reference is now made to Figure 4 in order to describe an example of how the device 1 of the invention operates.

The control module 8 manages three main stages.

5 In a first stage, the battery 2 is lightly discharged. The total voltage  $V$  across its terminals is below a limit voltage  $V_4$ . Consequently, the battery 2 needs to be recharged under rapid conditions by the charger 3 at constant voltage and at a current ( $I/BC =$   
10  $1/n$ ) that is as high as can be delivered by the charger 3, with this continuing until a voltage electrical reference value as determined by the control module 8 is reached, such that the battery has returned the value  $V_1$  that corresponds to being practically fully charged.  
15 This rapid charging stage is known as "bulk" charging.

The end of bulk charging is characterized firstly by a temperature slope  $DT_i$  greater than a threshold  $DT$ , and secondly by a voltage  $V_i$  across the terminals of at least a fraction  $i$  of the battery 2 (or of one of its secondary  
20 electrochemical cells 7-i) that is greater than  $V_1$ , and thirdly by a temperature  $T_i$  of at least a portion  $i$  of the battery 2 (or of one of its secondary electrochemical cells 7-i) that is less than a theoretical temperature  $T_1$ .

25 Consequently, the criteria for detecting the end of charging are, for example:

- $DT = KDT_1 + KDT_2 * I/BC;$

- if  $T_i < T_3$ ,  $V_1 = KV_1 + KT_1 * T_i + KC_1 * I/BC,$

30 where  $T_3$  is a temperature threshold that varies as a function of the relationship governing the detection threshold, which relationship may be different at high temperature and at low temperature;

- if  $T_i > T_3$ ,  $V_1 = KV_2 + KT_2 * T_i + KC_2 * I/BC;$  and

35 •  $T_i < T_1$ , where  $T_1$  is a high limit temperature for proper operation of the battery, beyond which its lifetime will be degraded.

Furthermore, alarms are preferably issued when the following conditions arise (with the purpose of such alarms being to inform the user of operation that is abnormal, whether temporarily or permanently):

- 5       ·  $DV_i > DV_1$ ; or
- $T_i > T_2$ ; or
- $\delta T_i > DTC$ , where  $\delta T_i$  represents the temperature difference between two portions of a battery.

In a second stage, the battery 2 presents a total  
10 voltage across its terminals which is greater than the limit voltage  $V_1$ . It is maintained in this state of charge either by causing the charger 3 to deliver a voltage  $V_2$  if it performs direct regulation, or else by chopping the current it delivers by means of the current  
15 limiter module 5 which controls the ON time of a relay so as to generate a mean current " $I_c/n$ " lying in the range  $I_c/2000$  to  $I_c/50$  for an alkaline system, for example. This stage of charging is referred to as "float" charging insofar as it is performed by the charger 3 under  
20 continuous charging conditions ("floating" charging). The value given to this current  $I_c/n$  depends on the electrochemical couple involved.

The theoretical voltage  $V_2$  can be defined by the relationship  $V_2 = KV_3 + KT_3 * T_i$ .

25       The end of floating charging is not characterized given that it is terminated by a subsequent discharge. However, it is preferable to issue an alarm in the event of the following conditions arising:

- 30       ·  $DV_i > DV_1$  in the event of dispersion between the states of charge within the battery;
- $T_i > T_2$  in the event of any tendency to thermal runaway; or
- $\delta T_i > DTC$  in the event of the battery not performing uniformly.

35       In a third stage, the battery 2 is deeply discharged as can happen if the charger 3 has failed for a long

period of time. This stage corresponds to a "discharged" state associated with a limit voltage  $V_3$ .

It is preferable to issue an alarm when the following conditions arise:

- 5       ·  $DV_i > DV_1$ ; or
- $V_i > V_3$  ( $V_3$  can be defined from  $V_2$  which is close to the open circuit voltage for state of charge of about 100%; for example  $V_3 = V_2 - OF_2$ ); or
- $T_i > T_2$ .

10       Furthermore, a return to the bulk charging stage in order to return to full charge can be triggered by the condition  $V_i < V_4$ , where  $V_4$  can also be defined from  $V_2$ ; for example  $V_4 = V_2 - OF_1$ . This makes it possible to avoid recharging batteries at high current when they are  
15       hardly discharged at all, and thus avoid heating them when there is no need to return quickly to a high state of charge.

      It is important to observe that the above-mentioned variable values depend on the electrochemical couple  
20       involved.

      An algorithm for managing the three above-described stages can begin with a first test (step 20 of Figure 4). In this step 20, the control module determines  $DV_i$  and  $DT_i$  on the basis of measurements delivered by the  
25       measurement module 6. In addition, it compares firstly  $DV_i$  with the threshold  $DV_1$ , secondly  $DT_i$  with the threshold  $DT$ , and thirdly  $T_i$  with  $T_2$  in order to verify the state of "health" of the battery.

      If the result of the test at step 20 indicates that  
30        $DV_i$  is greater than  $DV_1$ , or that  $DT_i$  is greater than  $DT$ , or indeed that  $T_i$  is greater than  $T_2$ , that means that there is an anomaly and that it is preferable to place the battery 2 in its floating charge state in order to attempt to make the anomaly disappear (while indicating  
35       that it has occurred and possibly also storing it). In a step 30, the control module 8 then generates an alarm which it preferably stores in one of its memories, so

that the content of the alarm can be analyzed a posteriori, making it possible to verify whether the problem that has arisen is one-off or is recurring. Thereafter, in a step 40, floating charging is started at voltage V2. The control module 8 then moves onto a step 50.

If the result of the test at step 20 indicates that  $DV_i$  is less than  $DV_1$ , that  $DT_i$  is less than  $DT$ , and that  $T_i$  is less than  $T_2$ , then the algorithm passes on directly to step 50.

Step 50 serves to verify whether the conditions indicating the end of bulk charging are satisfied. It consists in performing three tests on the voltage  $V_i$  and temperature  $T_i$  values of the secondary electrochemical cell 7-i. If the result of the test at step 50 indicates that  $V_i$  is greater than  $V_1$ , or that  $T_i$  is less than  $T_1$ , or indeed that  $DT_i$  is greater than  $DT$ , that means that the battery 2 is in an overcharged (or abused) state, i.e. it has gone beyond the state of bulk charging. The control module 8 then resets the alarm to its initial state (step 60), and then triggers a stage of floating charging at voltage V2 (step 70) in order to maintain the maximum charge state that has been reached. This returns to step 20.

In contrast, if the result of the test at step 50 indicates that  $V_i$  is less than  $V_1$ , that  $T_i$  is greater than  $T_1$ , or that  $DT_i$  is less than  $DT$ , then the algorithm passes onto step 80.

Step 80 is intended to verify whether the end of discharging can be reached. It consists in performing a test on the value of the voltage  $V_i$  of at least one of its portions in order to determine whether the battery 2 is 100% discharged. If the result of this test indicates that  $V_i$  is below a theoretical voltage  $V_3$ , that means that the battery 2 has discharged below the authorized limit. The control module 8 resets the alarm (step 90), and then generates an alarm (step 100) which it

preferably stores in one of its memories. Thereafter, depending on the application, either it leaves the battery 2 connected in spite of the risk of destroying it, or else it is decided to open the circuit.

5    Thereafter, the algorithm returns to step 20.

          In contrast, if the result of the test of step 80 indicates that  $V_i$  is greater than  $V_3$ , that means that it might be necessary to recharge the battery 2. In order to determine whether this is the case, the algorithm  
10    moves onto step 110.

          This step 110 consists in performing a new test on the value of the voltage  $V_i$  of the secondary electrochemical cell 7-i. If the result of this test indicates that  $V_i$  is greater than the theoretical voltage  
15     $V_3$ , but less than a theoretical voltage  $V_4$ , that means that the battery 2 has been discharged sufficiently to allow it to be recharged in bulk charging mode. The control module 8 resets the alarm (step 120) and then requests a stage of bulk charging under voltage  $V_1$  (step  
20    130), thereby returning to step 20. The value of OF1 must then be great enough to allow bulk charging mode to be restarted for depths of discharge greater than 5%. In addition, the value of OF2 must be high enough to be sure of detecting the end of discharging.

25    In contrast, if the result of the test in step 110 indicates that  $V_i$  is greater than  $V_3$  and  $V_4$ , that means that the algorithm remains in bulk charging mode. Since the situation is "normal", the algorithm returns to step 20.

30    The above-described algorithm (or method) relies on making comparisons between thresholds (or limits) and "local" measurements performed on a portion  $i$  of the battery 2. However, the algorithm could be applied in succession to a plurality of portions of the battery 2,  
35    or even to each of its secondary electrochemical cells 7-i. Similarly, the algorithm may be applied to the entire battery 2. Under such circumstances, it is necessary to

measure the voltage across the terminals of the battery 2 and the mean temperature of the battery.

Furthermore, a control device is described above that is separate from the battery and that is connected thereto. However the control device may be directly  
5 integrated in the battery unit.

In addition, the control device may be arranged in the form of an electronics card, e.g. in the form of a sheet suitable for integrating in the battery  
10 connections.

The invention is not limited to the embodiments of the control device and the battery described above, purely by way of example, but covers any variant that might be envisaged by the person skilled in the art  
15 within the ambit of the following claims.